History of Monopulse Radar

in the

USSR

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ABSTRACT

Monopulse radars have played an important role in air and missile defense systems since the development of the monopulse technique in the late 1940s. This paper outlines the application of monopulse radars in Russian defense systems, starting with the Moscow ABM system and continuing in instrumentation and air defense radars now widely deployed in Russia and elsewhere.

SUMMARY

In the USSR one of the first projects to develop monopulse radar has been done in OKB 30 [1] attached to the Ministry of Radio Manufacturing Industry, later reorganized into the Scientific Research Institute of Radio Equipment Manufacturing (NIIRP). The design work started in 1954 and the first monopulse radar was developed for the ABM system for the Moscow area, "A-35." The system incorporated the command post, four sector long-range radars, eight fire control complexes and 64 interceptor missiles equipped with nuclear warheads and designed to perform exo-atmospheric interception of ballistic missiles. In 1952 at the test range in Sari-Shagan (Kazakhstan), the work to develop the experimental version of the A-35 system began. This system had one monopulse long-range radar, three fire control complexes, and the interceptor missile (the General Designer was P.D. Grushin). On the fourth of March, 1961, this interceptor missile was the first in the world to destroy the warhead of a ballistic missile, launched from the test range KapustinYar (near Volgograd, formerly Stalingrad).

In 1962, the project to create the A-35 ABM system for the Moscow region began. Simultaneously its experimental prototype, the system "Aldan," was being built at the Sari-Shagan test range. The General Designer of the A-35 system was G.V. Kisunko. The tests of the "Aldan" system were completed in 1974 and the tests of the A-35 system in 1978.

In 1975, the work to develop a new Moscow region ABM system began. The General Designer of this system is Dr. A.G. Basistov. The tests of this system were completed in 1990. It incorporates a command post, the multifunctional radar "Don," and 100 interceptor missiles.

The evolution of monopulse radars in 1950-1990 is shown in Figure 1, on next page. This diagram is not absolutely complete because it does not depict some works done to develop airborne and naval monopulse radars.

MONOPULSE RADARS FOR ABM SYSTEMS

Radars for the "A-35" and "Aldan" Systems

The fire control complex of the "Aldan" and "A-35" systems incorporated three amplitude sum-difference monopulse radars. One of them detected ballistic missiles using the designation data from long-range early warning radar and performed tracking and target discrimination (classification). The other two radars performed guidance of the interceptor missiles. The detection radar operated

[1] OKB: osoboe konstruktorskoe bjuuro (special design bureau).

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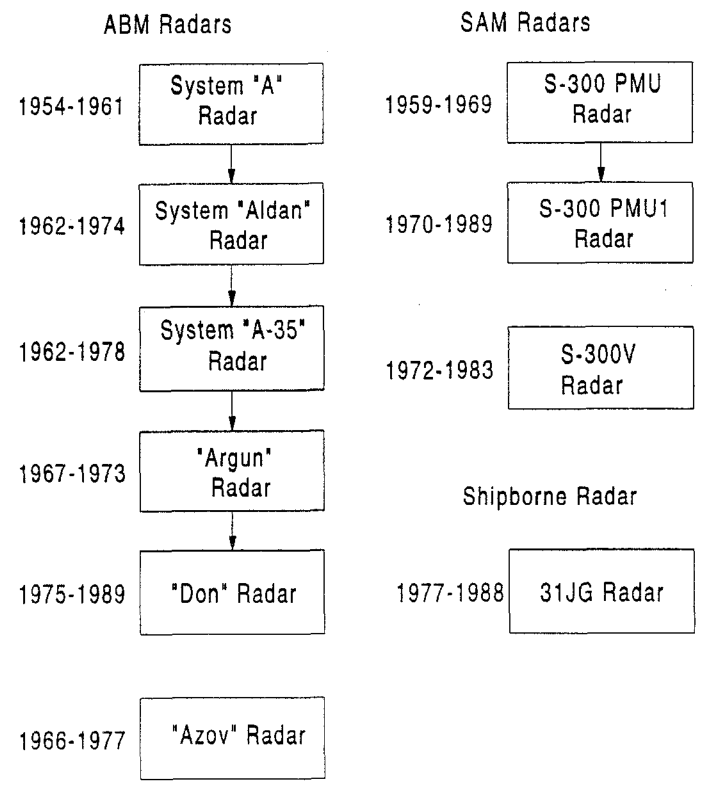


Fig. 1. The Evolution of Monopulse Radars in the USSR, 1950-1990

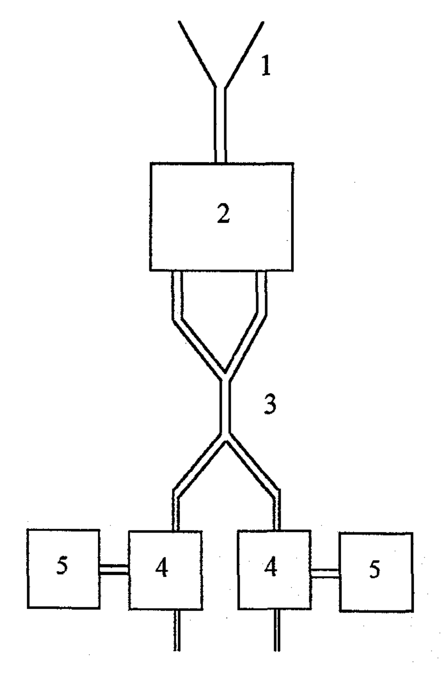
in the lower portion of decimeter wave band and was capable of detecting two targets at a range of more than 1000 km. The antenna was of the Cassegrain type and had a main reflector (18m diameter), two moveable subreflectors and a four-horn feed. The mechanical rotation of the antenna in both planes ensured the complete hemispherical coverage. The beamwidth is about 30 arc min, and the motion of subreflectors provided electromechanical scanning capability within ±30 arc min limits.

The transmitter generated the pulses with a width of 6 μs and 0.5 μs (the latter for ranges less than 600 km). The range resolution is about 80m, the angular resolution is about 30 arc min. The rms error of range measurement is 15-20m, of angular measurement is about 6 arc min. The output signals in the sum and difference channels passed through an analog-to-digital converter and went to a central computer for processing.

The guidance radar also operated in the lower portion of decimeter wave band using signals from a transponder mounted onboard the interceptor missile. The antenna was of the Cassegrain type and had a main parabolic reflector (9m diameter), moveable subreflector, and four-horn feed. The antenna system formed, initially, a broad beam for interceptor missile lock-on and then a narrow beam to track the missile in the flight phase. The radar had a capability to track and guide one intercept missile at the range up to 600 km. The range measurement accuracy was about 10m, the angular measurement accuracy 6 arc min.

The signal processing was performed by the computer. The output information passed to the command post and was used for interceptor missile guidance and to determine the time to explode the nuclear warhead.

The main difference between detection radars of the "A-35" system and "Aldan" was that the latter had a single fixed subreflector. The guidance radars of both systems had practically no difference.



1 - Partial horn of monopulse feed
2 - Waveguide circuit of polarization forming
3 - Slotted bridge
4 - T/R switches
5 - Receivers of the first and second polarizations

Fig. 2. Block Diagram of Dual-Polarization Network for the "Argun" Radar

The "Argun" Radar

The experimental monopulse radar "Argun" (the Chief Designer is A.A. Tolkachev) was one of the first phased array radars designed in NIIRP. The design began in the late 1960s and the tests were performed in 1973. The radar is located at the Sari-Shagan test range and up until now is used as the instrumentation radar facility. The radar is fully automated and the signal processing and the control functions are performed by the central computer and special digital units. The antenna system includes a space-fed phased array mechanically rotated in both planes and monopulse four-horn feed.

The diameter of the antenna face is 18m. The transmitter generates pulsed linear frequency modulated waveforms. The basic performance of the "Argun" radar (waveband, range, resolution) are approximately the same as for the detection radar of the "Aldan" system. The main distinctive feature of the "Argun" radar is that it is capable of operating with both orthogonal circular polarizations in

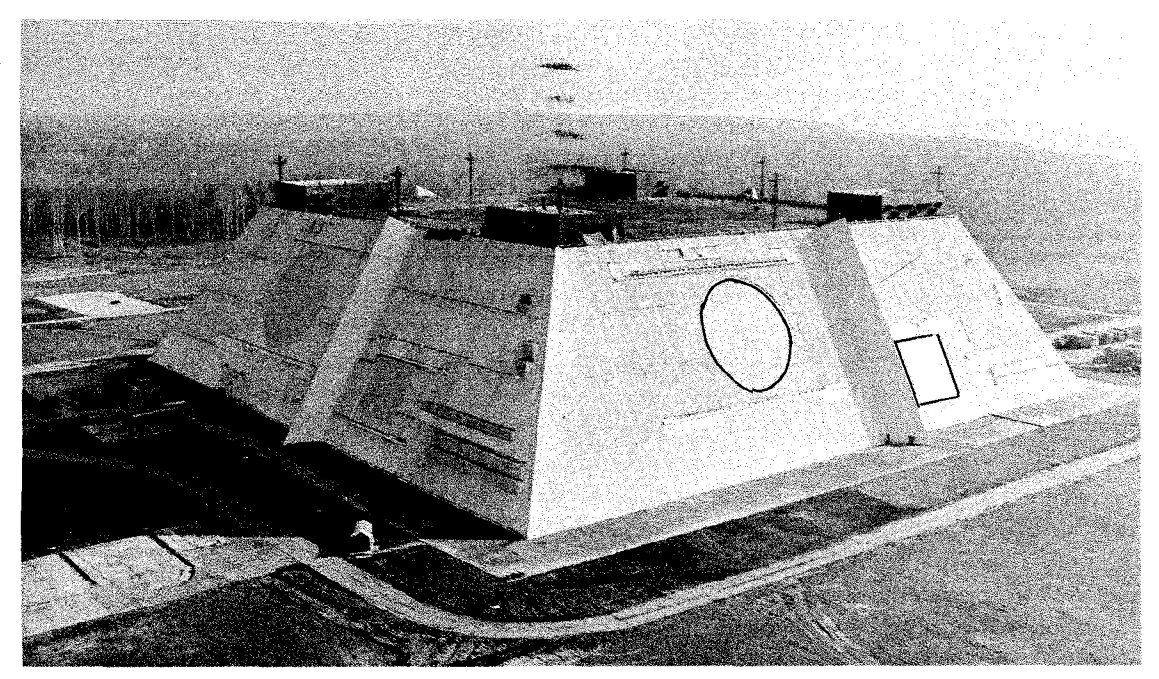


Fig. 3. General View of the "Don" Radar.
The Circular Receiving Arrays and Rectangular Transmitting Arrays are Outlined

the transmit and receive modes, so the full polarization scattering matrix of the targets can be measured. To form the double-polarization signals the configuration cited in Figure 2, on previous page, is employed in each of the four elementary channels. The radar was modified several times during the service period of 1973-1995.

The "Azov" Radar

The "Azov" radar was developed in the 1970s in the "Almaz" company (the General Designer is B.V. Bunkin). It was designed to acquire multielement ballistic missiles using designation data and to guide an interceptor missile of the "Sprint" type at the atmospheric portion of the ballistic missile trajectory. This radar is a monopulse sum-difference system operating in the centimeter wave band. The antenna consists of transmitting and receiving phased arrays mounted on a single rotating pedestal capable of steering the beam in the entire upper hemisphere. The electronic scanning sector is equal to 5° in azimuth and 4° in elevation. The beamwidth is about 1°. The pulsewidth is about 400 μs, and the transmitter is capable of generating different types of the waveforms: amplitude-modulated, frequency-modulated and phase-coded ones.

The signal processing is performed in a multichannel correlation-filter receiver with the separate channels for the specified ranges and radial velocities. To form the tracker error signal offset-tuned channels in the correlation-filter receiver are used in range and doppler frequency coordinates. The sum and difference signals from the output of the sum-difference bridge are passed to the corresponding channels of the receiver. The signals from the output of the phase detector are converted to digital form and are passed to the computer that determines the angular coordinates of the target, using the monopulse method. Trajectory tracking is performed using modified Kalman filtering taking into consideration the acceleration of the reentry targets.

The radar operational range is about 1000 km. The range resolution is about 100m, the angular resolution is about 1°, the doppler resolution is about 100 m/s. The rms range measurement error is 7-8 meters, angular measurement error is about 6 arc min, and radial velocity measurement error is about 3 m/s.

The "Azov" radar was not included in the ABM system. Without a guidance channel it was installed at the Kamchatka Peninsula, and since 1977 has been used as an instrumentation radar.

"Don" Multifunction Radar

The "Don" multifunction radar is incorporated in the modified ABM system of the Moscow area and installed near the city of Pushkino to the north of Moscow. The radar was developed in the period from 1973-1989 in the Radio Engineering Institute named after academician Mints (the General Designer is V.K. Sloka). The main functions performed by the radar are to detect, track and discriminate (classify) ballistic targets, and to guide the interceptor missiles. The radar is located in the building having the shape of the tetrahedral truncated pyramid (Figure 3).

On each edge of the building the space-fed transmitting and receiving phased arrays of large module configuration are located. The receiving array is circular (16m diameter), the transmitting one is rectangular (7 × 8 meters). The receiving antenna can form several

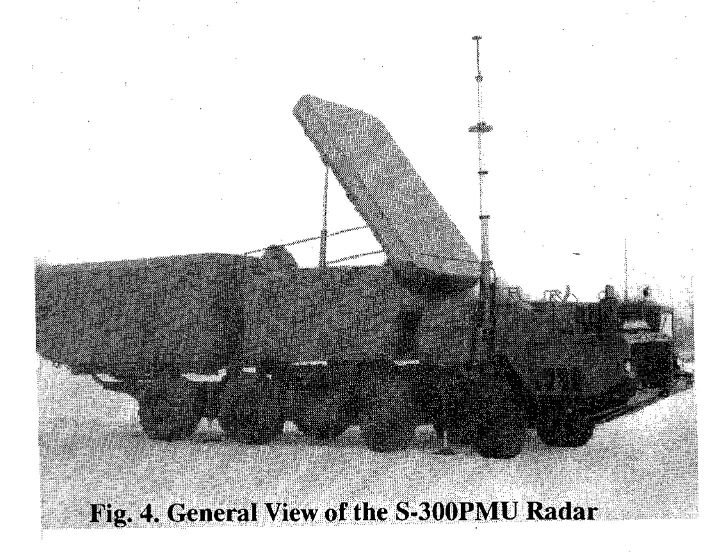


Fig. 4. General View of the S-300PMU Radar

independent groups of the beams for monopulse angle-sensing. The transmitter generates the pulsed signals of different duration and with different intrapulse modulation (linear frequency-modulated and phase-coded waveforms). The digital signal processing is performed at the intermediate frequency by a high-speed computer (more than a billion operations per second).

The radar operates in the centimeter wave band, it has the operational range up to several thousand kilometers, and it possesses high capabilities in target resolution, accuracy, jamming immunity, and target capacity.

MONOPULSE RADARS FOR SURFACE-TO-AIR MISSILE SYSTEMS

Radar for the S-300PMU System

The multichannel, mobile S-300PMU SAM missile system was designed in the "Almaz" company in 1959-1969 (the General Designer is B.V. Bunkin). It is designed to destroy aircraft, cruise missiles and other air targets flying at altitudes from 25m to their effective ceiling. The SAM battery incorporates a monopulse multifunction phased array radar (Figure 4), up to twelve launchers holding four missiles each (Figure 5) and the surface-to-air missiles. The SAM battery provides simultaneous engagement of up to six targets with guidance of up to two missiles to each of these targets.

The radar consists of the sum-difference monopulse radar set and the engagement control station mounted on a common chassis. The radar operates in the centimeter waveband. It provides target tracking and high accuracy of missile guidance in an environment of clutter and heavy ECM. The antenna consists of a transmit-receive phased array with digital beam steering. The beamwidth is about 1°. The aircraft detection/range is up to 130 km. The range measurement accuracy is about 10 m, the angle measurement accuracy is of an order of several arc minutes. The signals from the output of the receiver pass

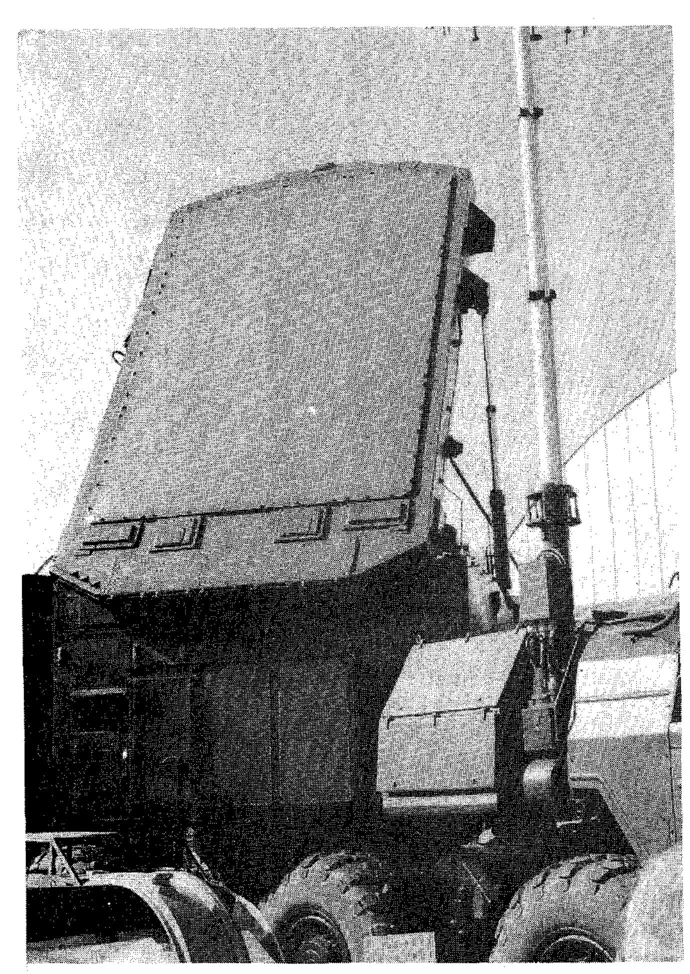


Fig. 5. General View of the S-300PMU1 Fire-Control Radar

to the analog-to-digital converter and subsequent signal processing is performed by the computer.

The engagement control station includes the operator consoles, multiprocessor computers and built-in functional test equipment. During autonomous combat operations the radar receives designation data from the 3D surveillance radar 36D6 attached to the battery.

Radar for the S-300PMU1 System

The mobile multichannel SAM system S-300PMU1 was designed to defend the most important state assets and to create air defense fences to defend against mass attacks of modem airborne attack vehicles, including strategic and tactical aircraft, cruise missiles, air-to-surface missiles, tactical and operational-tactical ballistic missiles. The main components of the system are also used for navy air defense.

The S-300PMU1 system has been developed by the "Almaz" company in 1979-1989 and it is a further development of the S-300PMU system (the General Designer is A.A. Lemanskiy). The system includes a monopulse radar (Figure 5) and up to twelve launchers with four missiles each. The sum-difference amplitude monopulse radar detects and tracks the targets, and

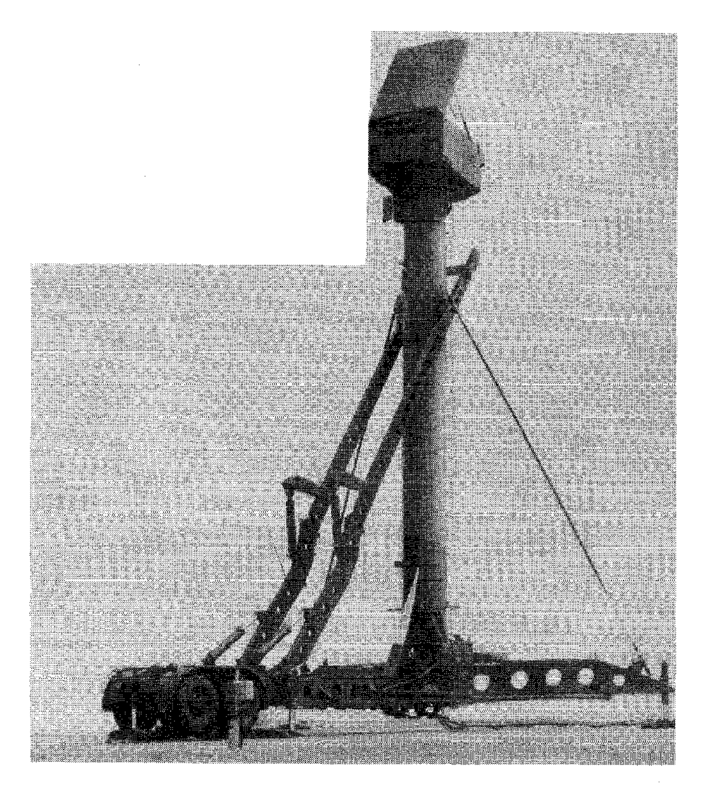


Fig. 6. The Radar Set of the S-300 PMU1 System on a Special Tower

determines the succession in which the targets are engaged. The radar also locks-on and tracks surface-to-air missiles, and illuminates the targets to ensure the operation of semiactive homing seekers and proximity fuzes.

The radar operates at the centimeter wave band and consists of the radar set (antenna, transmit-receiving equipment, pedestal) and the engagement control station (multiprocessor computer, operator's consoles, signal processor, communication and data recording equipment, autonomous power supply sources) mounted on a common chassis.

The antenna system is a transmit-receive phased array employing phase control in each element of the array, providing flexible beam steering. The size of the antenna is 2.5 × 3.0 m, the beamwidth is about 1°. In a forest or in rugged country the radar set can be mounted on a special tower (Figure 6).

The transmitter generates pulse burst waveforms at high pulse repetition frequency, increasing the efficiency of operation in the presence of underlying surface clutter, precipitation, and chaff. The digital signal processing is performed at the intermediate frequency. The detection range on aerodynamic targets is about 200 km, the detection range of the missiles is about 100 km. The radar has a high resolution and accuracy: range measurement accuracy is about several meters, angle measurement accuracy is about 1°.

The missile guidance is performed using the commands from the radar and based on "track-via-missile" principle. The maximum range to destroy the target for aircraft is 120-150 km, for ballistic missiles is 40 km, and for strategic cruise missiles is 28-38 km. The maximum altitude to destroy the target is 27 km, the minimum is 10m.

Radar for the S-300V System

The multichannel, mobile, S-300V SAM system is designed to protect army units and important battlefield targets against tactical and operational-tactical ballistic missiles and air-breathing threats. The system has efficient electronic countermeasures protection and can intercept simultaneously up to 24 targets guiding up to two missiles from one launcher and up to four missiles from two launchers to each target. The system was designed in 1972-1983 by the "Antey" company (the General Designer is V.P. Efremov).

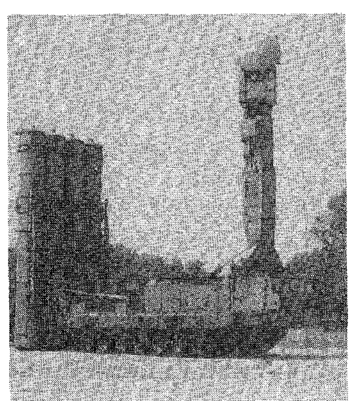
The system incorporates a target detection and designation unit and a fire unit. The target detection and designation unit includes the command post, one 360° surveillance radar, and one sector scanning radar. The fire unit has a multichannel missile guidance radar, up to six launchers for two types of missiles and launcher-loader machines.

In the process of combat operation the surveillance radar detects up to 200 targets and transmits the data to the command post. The sector scanning radar provides the regular scanning of the sector of 90° in azimuth and 50° in elevation, detects the targets in this sector and provides track formation. If the high speed target is detected, the detection is followed by the track initiation (the maximum number of tracked trajectories is 16). Provision is made for target search using designation data received from the command post.

The sum-difference amplitude monopulse guidance radar detects the target assigned by the command post, measures its coordinates, and controls the operation of six launchers. It also provides the observation of the sector close to the ground in which low-altitude targets are likely to appear. The radar operates in the centimeter wave band. The antenna system is based on space-fed transmit-receive phased array. The size of antenna 2.5 × 2.5m. The array consists of 10,000 elements. The beamwidth is about 1°. The transmitter can generate different types of the quasi-continuous linear frequency-modulated waveforms with variable duration. The three-channel receiver forms the sum and difference signals using the monopulse technique. The signals from the output of the phase detector are converted into digital form and the subsequent processing is performed by the computer.

The detection range of the aerodynamic target with RCS = $2m^2$ is about 180-190 km. The detection range of the missiles with RCS = $0.02m^2$ is up to 100 km. The accuracy of the range measurement is several meters, the accuracy of the angle measurement is about 1-2 arc min. The range resolution is about 60m, the angle resolution is about 6 arc min. The employing of quasi-continuous signal





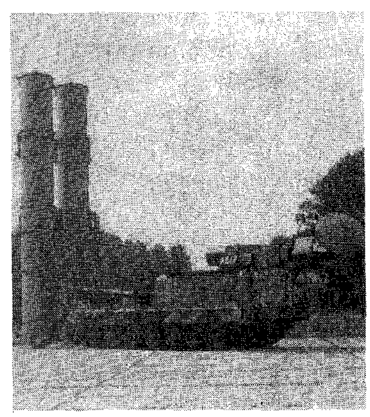


Fig. 7. The General View of the Guidance Radar of the S-300V System

ensures high doppler velocity resolution. The guidance radar is mounted on the tracked chassis (Figure 7).

The US surface-to-air missile system analogous to the S-300PMU and S-300V systems is the "Patriot." Some of the advantages of S-300 systems in comparison with "Patriot" are:

1. The missile is vertically launched;
2. The radar set can be lifted up to the special tower;
3. The maximum intercept range is longer;
4. Coherent pulse trains are used; and
5. The reaction time is less.

MONOPULSE – SHIPBORNE RADAR

In 1977-1988, the Scientific Research Institute of Radio Equipment Manufacturing (NIIRP) built and tested shipborne sum-difference monopulse radar 31J6 (the Chief Designer is V.V. Gruzdec). It was designed to operate against different types of space objects: rockets, ballistic missiles, satellites, etc. The main task of the radar is to detect the targets, measure their coordinates, determine the trajectories of the targets and their impact points, to obtain information about the scattering characteristics of the targets (RCS, range profiles, the parameters of plasma trails in an atmosphere), and provide classification and discrimination of observed targets. Provision is made for operating in jamming conditions with reduction of jamming efficiency.

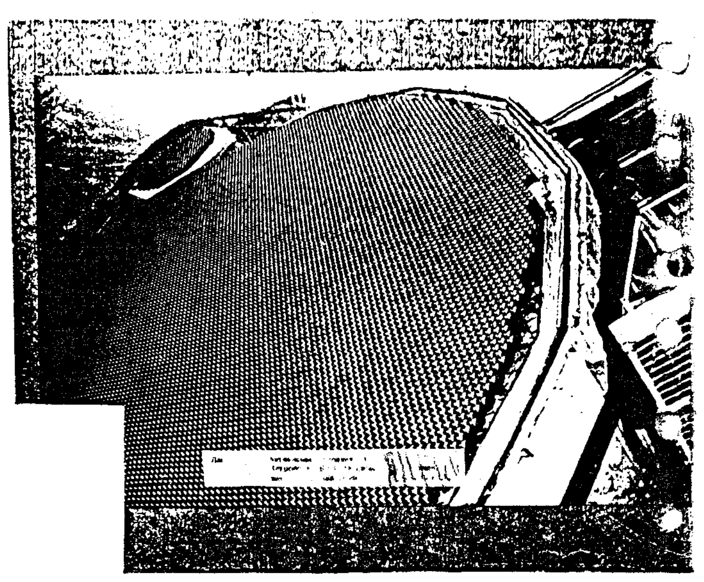


Fig. 8. The Antenna of the 31J6 Radar

The radar operates in centimeter wave band against the targets with RCS from 0.001 m^2 up to 1000 m^2. The antenna-waveguide system (Figure 8) consists of the main phased array and two small phased arrays. All arrays are space-fed, the diameter of the main array is about 9m, the number of elements and phase shifters is more than 10,000. The smaller arrays provide suppression of antenna sidelobes and active jamming if employed; the beam steering and phase shifters control is done by the special computer. The beam steering unit and coordinate transformation unit provide full upper hemisphere coverage and the stabilization of the beam under the conditions of rough sea (roll). The sector of electronic scanning is up to 120°. The automated electronic system of beam stabilization compensates the effects introduced by the roll and the deformations of the ship and antenna structures. It includes the navigation system, the optical deformation measurement system and beam steering unit.

The transmitter is based on klystrons and crossed-field waveguide amplifiers forming an amplifier chain configuration. It provides output power more than 10MW. The transmitter generates a variety of waveforms: single pulses with duration from 1 to hundreds of μs, pulse bursts with the duration up to 1 ms, and double combinations.

The receiver is of the multichannel monopulse configuration. It employs low-noise amplifiers with the noise temperature less than 100K.

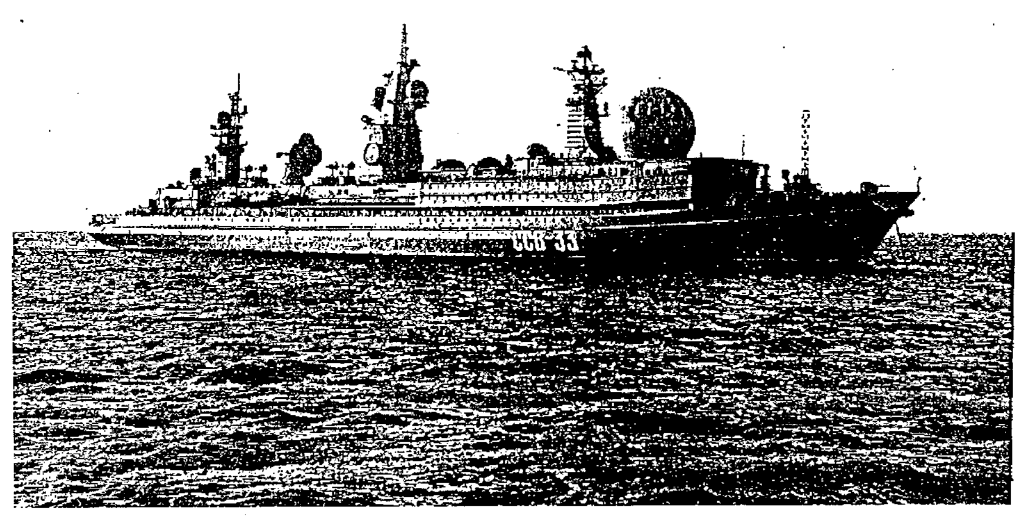


Fig. 9. The Ship SSV-33

Operation of the radar is automated with a computer. The software includes 20 packages providing for obtaining and processing of radar data, control and maintenance of the equipment. The computation capability of the computer is 5,000,000 operations per second, the RAM capacity is 1,000,072 of the digital words, the ROM capacity is up to 500 Mbytes.

The detection range of the radar is 10 to 2000 km. The range measurement errors are less than 10m, the angle measurement errors are about 1°. The range resolution is 100 to 1 m, the angle resolution is 1°. The throughput capability is several tens of targets simultaneously. The weight of the radar is more than 350 tons, power supply consumption is about 5MW, it is mounted on the ship SSV-33 (Figure 9). It is the most powerful and complicated shipborne radar in the USSR. The analogues US radar is "Cobra Judy." The main advantage of the 31J6 radar in comparison with the "Cobra Judy" is that it has wider scope of the tasks it is able to perform, it can operate fully autonomously ("Cobra Judy" needs the designation data from the ground-based radar) and it provides the entire upper hemisphere coverage due to the possibility of mechanical rotation of phased array in both planes.

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